1447335

PATENT SPECIFICATION

(11) 1447335

(21) Application No. 49441/74 (22) Filed 15 Nov. 1974
(31) Convention Application No. 132547/73 (32) Filed 28 Nov. 1973 in (19)
(33) Japan (JA)
(44) Complete Specification published 25 Aug. 1976
(51) INT CL² C21D 1/62
(52) Index at acceptance
C7N 6 8

(54) METHOD OF COOLING A HIGH TEMPERATURE OBJECT BY HIGH TEMPERATURE WATER

(71) We, NIPPON KOKAN KABUSHIKI KAISHA, a corporation organised and existing under the laws of Japan, of 1-1-2, Marunouchi, Chiyoda-ku, Tokyo, Japan, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to a method of cooling high temperature objects, particularly slabs for plates, hot rolled plates, continuously cast slabs, etc., with the use of high temperature water.

The conventional cooling methods for cooling such high temperature objects employ low temperature water as a coolant, and the high temperature objects are cooled by immersing the objects in the low temperature water or by spraying the low temperature water against the high temperature objects through a nozzle or nozzles. Consequently, where a large cooling capacity is required, the use of a large quantity of water is necessary. Thus, in order to reduce the quantity of water required, a mist cooling method has been developed in which a spray of water shot out by means of air is directed against an object to be cooled for cooling it. A disadvantage of this cooling method is that, while the quantity of water required may be reduced, a large quantity of air under high pressure is necessary. Consequently greater cooling capacity requires larger equipment since a larger air compressor, air holder, etc. as well as an increased piping are required. Moreover, in the conventional method the pressure fluctuation of a two-phase flow of water and air which is directed against an object to be cooled is so great that the jets of flow pulsate and thus it is difficult to ensure a constant flow rate.

With a view to overcoming the foregoing difficulty, the present invention provides an improved cooling method which eliminates the use of air and which ensures a large cooling capacity with reduced water requirements.

The present invention provides an improved cooling method which employs a compact equipment to provide a stable blowing rate of two-phase flow with reduced pressure loss.

In accordance with the present invention, there is thus provided an improved cooling method in which high temperature water heated in a pressure vessel having heating means, to a temperature above 100°C but below its boiling point in the vessel, whereby it remains in liquid phase, is blown out of the vessel through at least one nozzle by virtue of the internal pressure of the pressure vessel, and the resulting high-speed two-phase flow consisting of steam and fine water particles is directed in jet-form against the surface of a high temperature object to cool the object.

The features and advantages of the present invention will become readily apparent from considering the following detailed description in conjunction with the accompanying drawings, in which:

Fig. 1 is a schematic diagram of the simplest basic form of a system for performing the novel cooling method of the present invention;

Fig. 2 is a schematic diagram showing another form of the system for performing the method of this invention;

Fig. 3 is a schematic diagram showing still another form of the system for performing the method of the invention, wherein waste heat is utilized;

Fig. 4 is an equilibrium diagram for the internal pressure of a pressure vessel and the temperature of high temperature water;

Fig. 5 is a diagram showing the results of a comparison between the cooling method of this invention and the conventional cooling method; and

Fig. 6 is a diagram showing the results of a comparison on the uniformity of mechanical property of the cooled product by the cooling method of the invention and that cooled by the conventional method.

The present invention will now be described in greater detail with reference to the accompanying drawings.

Referring first to Fig. 1, there is illustrated the basic form of a system for performing the method of this invention, wherein high temperature water contained in a pressure vessel 101 and heated above 100°C therein is blown outside through a nozzle 102 against an object 104 to be cooled while the quantity of flow thereof is being controlled by means of a control valve 103 mounted in the flow line. In Fig. 1, numeral 105 designates a pressure gauge which is mounted on the pressure vessel, and numeral 106 designates a temperature gauge which is also mounted on the pressure vessel.

Fig. 2 illustrates another form of the system for performing the method of this invention, wherein a heating steam pipe 208 for supplying a high temperature steam is connected to a pressure vessel 201 through a steam control valve 209, and a water supplying pipe 210 is also connected to the pressure vessel 201 through a supply control valve 211. The pressure vessel 201 is further provided with a drain valve 213, a pressure gauge 205, a temperature gauge 206 and a level gauge 207, and the high temperature water heated by hot steam to a temperature above 100°C in the pressure vessel 201 is blown outside against an object 204 to be cooled through at least one nozzle 202 through a flow meter 212 and a control valve 203. The heating of the high temperature water in the pressure vessel 201 may also be accomplished by means of other heat sources such as an electric heat, etc.

Fig. 3 illustrates still another form of the system for performing the method of the invention which is identical with the system of Fig. 2 excepting that waste water recycling means are added to ensure an improved thermal efficiency. In Fig. 3, a drainage pit 214 for collecting the waste water is arranged below the object 204 to be cooled so that the waste water is collected, passed through piping and stored in a drain tank 215, and the thus collected and stored water is recycled into the pressure vessel 201 by means of a water supply pressure pump 216 through a strainer 217 and through a recycling water supply control valve 218 and a piping 219.

In accordance with the present invention, the internal pressure of the pressure vessel is in boiling equilibrium with the temperature of high temperature water as shown in Fig. 4, and therefore if the temperature of high temperature water is (100+t)°C, then the corresponding pressure becomes (1+P) kg/cm^2 when the atmospheric pressure is of the order of 1.0 kg/cm^2. When such a high temperature water is blown outside into the atmosphere of a pressure of the order of 1.0 kg/cm^2, the temperature of the water is reduced to 100°C at the outlet end of the nozzle and a part of the high temperature water is evaporated. In this case, weight x and volume y of evaporated steam per unit quantity of the high temperature water are given by the following equations:

$$x=\frac{100+t-100}{\Delta Q}=\frac{t}{\Delta Q}=\frac{t}{540}$$
(kg/l of high temperature water) (1)

$$y=a\,.\,x=1600\,x=\frac{1600}{540}\,t=2.96\,t$$
(l/l of high temperature water) (2)

where ΔQ is the heat of evaporation of water which is 540 kcal/kg (or lit), and a is the volume ratio between steam and water at 100°C which is 1600. Assuming now that high temperature water of 150°C is used, then the corresponding pressure is given as 4.85 kg/cm^2 from the equilibrium diagram of Fig. 4. Thus, by substituting the corresponding values into the above equations, we obtain the steam weight x and steam volume y per unit quantity of the high temperature water, as follows:

$$x=0.0903,\ y=148$$

Consequently, when the high temperature water is blown outside at the rate of 20 l/min, it is then vaporized at the rate of about 1.8 l/min and the volume of resulting steam is 2.7 m^3/min. As a result, the volume of the two-phase flow is the same with that obtainable when water of about 18 l/min is discharged by means of air of 2.7 m^3/min. However, the velocity of the jet is higher in the case of the present invention.

While this jet velocity is controlled by adjusting the opening of the control valve, the jet velocity may also be controlled by adjusting the temperature of high temperature water, since the weight of steam per unit quantity of the high temperature water changes with the temperature of the high temperature water as shown in Fig. 4.

On the other hand, the cooling capacity is increased by virtue of the fact that since the water at 100°C impinges at a high velocity against the surface of an object to be cooled, the formation of vapor film is prevented and a higher evaporation rate is obtained than in the case where low temperature water is employed.

Next, the thermal balance in the method of this invention will be described in detail. In case an ordinary industrial waste water is recycled, the required heat supply Q_1 for cooling by high temperature water will be given as follows:

$$Q_1=(t_2-t_1)\ \text{kcal/kg}$$
of high temperature water (3)

where t_1 is the feed water temperature (°C) and t_2 is the temperature (°C) of the high temperature water. In practice, however, for purposes of economy the waste hot water resulting from the cooling method of this invention is collected and recycled. In this case, since the temperature of the water particles blown outside through the nozzle is of the order of 100°C and since the transfer of heat at the surface of an object to be cooled takes the form of boiling heat transfer, a part of the high temperature water is evaporated at the heat transfer surface and the remaining high temperature water flows down while remaining at the temperature of 100°C. By reducing the heat loss during the circulation, the temperature of this high temperature water may be maintained above 90°C. In this case, it is enough to supply fresh water in an amount just to make up for the evaporation loss and the circulation loss. Thus, if the circulation loss is neglected, a supplemental water quantity r (kg of water/kg of high temperature water) and a supplemental heat quantity Q_2 (kcal/kg of high temperature water) are given as follows:

$$r=x+z \qquad (4)$$

$$Q_2=(t_2-t_1)(x+z)+(t_2-t_3)(1-x-z) \qquad (5)$$

$$Q_1-Q_2=(t_3-t_1)(1-x-z) \qquad (6)$$

where t_3 is the temperature of recycling water, x is the weight ratio of steam (kg/kg of high temperature water) evaporated while the high temperature water is being blown outside through the nozzle, and z is the weight ratio of steam (kg/kg of high temperature water) evaporated while a high temperature object is being cooled.

If we have $t_1=30°C$, $t_2=150°C$, $t_3=90°C$, $x=0.09$ and $z=0.10$, then substitution into the above equations gives $Q_1=120$ kcal/kg of high temperature water, $Q_2=72$ kcal/kg of high temperature water and $r=0.19$. Thus, the required heat quantity is about 60% and the supplemental water quantity is about 20% of total water in the cooling system.

It will thus be seen from the foregoing description that the cooling method according to the present invention has among its advantages the fact that when the internal pressure in a pressure vessel is tending to decrease during the blowing of the high temperature water, a part of the high temperature water is evaporated within the pressure vessel to maintain the internal pressure at a predetermined value with the result that a highly stabilized blowing rate is ensured, and the high temperature water is conveyed in liquid state up to the nozzle end thereby reducing the pressure loss in the pipe line and maintaining the nozzle pressure high.

Another advantage of the method of the invention is that while the volume of the vaporized steam is very great, the high temperature water is maintained in liquid form within the pressure vessel thus requiring only a compact equipment and eliminating the use of a large capacity air holder employed with the conventional method in which mist is produced by means of air for cooling purposes.

A further great advantage is that there is no need for a cooling tower which cools the cooling water.

Thus, the present invention has a good industrial utility value.

The following examples describe in greater detail the advantages of the improved cooling method in accordance with the present invention.

Example 1

Fig. 5 shows a comparison of the cooling rates of the conventional water-spray cooling method and the cooling method of the present invention employing high temperature water. Steel plates having a thickness of 32 mm were used, and each plate was cooled on both sides thereof, and the plate temperature was measured by means of a thermocouple embedded in the plate to a depth of 2 mm from the surface and another thermocouple also embedded in the plate to the middle of its thickness. Chain lines S_1 and C_1 indicate the cooling rates of the conventional water-spray cooling method, and solid lines S_2 and C_2 indicate the cooling rates obtained with the cooling method of the invention employing high temperature water. The curves S_1 and S_2 show respectively the rate of cooling of the plate whose temperature was measured at the position 2 mm beneath the surface of the plate, while the curves C_1 and C_2 show respectively the cooling rate of the plate whose temperature was measured at the position middle of the plate thickness. As will be apparent from Fig. 5, the cooling method of this invention is highly effective as compared with the conventional method.

Further, when the quantity of water used in the method of this invention was gradually reduced to obtain the water requirements that would ensure the similar curves of cooling rate as obtained with the conventional water-spray cooling method, the resulting water quantity was one fifth of the quantity required with the conventional cooling method. In other words, the cooling method of the invention employing high temperature water could ensure the same cooling effect as the conventional water-spray method with only one fifth of the water quantity which is required in the conventional method.

Example 2

Heat treated steel plates were cooled by both the cooling method of the invention and the conventional water-spray cooling method, and a comparison was made on the efficiency of the two methods. The following Table 1 shows the results of the comparison.

TABLE 1

	Plate thickness (mm)	Water qty (1/min. m^2)	Ratio of water qty	Temperature (°C) Initial temperature	Final temperature
Water-spray method	40	2000	5	920	380
High temperature water method	40	400	1	920	390

In the above Table 1, the temperatures were measured at the surface of the steel plates. It will be apparent from Table 1 that the cooling method according to the present invention requires only one fifth of the water supply required by the conventional method in accomplishing the same cooling effect.

Example 3

To demonstrate the stable discharging of high temperature water in the cooling method of the invention and hence the high degree of uniformity of the mechanical property of the plates cooled by this cooling method, the distribution of yield strength in the longitudinal direction of steel plates cooled by both the method of this invention and the conventional method were examined. Fig. 6 shows the results of the examination. In Fig. 6, the abscissa indicates the longitudinal dimension of the cooled steel plate calibrated in percentages with one end of the plate being taken as 0 and the other end being taken as 100 to show the measuring positions. It will be seen from Fig. 6 that as compared with the steel plate cooled by the conventional water-spray cooling method, the degree of deviation of the yield strength value of the steel plate cooled by the cooling method of this invention is small.

Example 4

In a cooling operation, it has been usual to recycle cooling water as much as possible for repeated use of the cooling water. Consequently, the quantity of water required for cooling purposes differs from that of the supplemental water required to make up for the loss. The following Table 2 shows the results of a comparison made on these water quantities between the conventional water-spray cooling method and the cooling method of the present invention.

TABLE 2

	Ratio of water requirement	Percentage of unrecovered water quantity
Water-spray method	5	10% (of which 9% was a loss during cooling)
High temperature water method	1	20% (of which 19% was evaporation loss)

The amount of cooling water required by the cooling method of the invention was about one fifth of that required by the conventional cooling method, whereas the amount of supplemental water was

$$(1\times20\%)/(5\times10\%)=2/5$$

of that required by the conventional method. Thus, these water requirements of the method of this invention were far less than those of the conventional method. Reduced water requirements as stated above have the effect of permitting the use of pumps having the correspondingly lowered horse powers for recycling the cooling water.

WHAT WE CLAIM IS:—

1. A method of cooling a high temperature object by jetting a stream or streams of coolant against the surface of said high temperature object, characterized in that high temperature water heated in a pressure vessel having heating means to a temperature above 100°C but below its boiling point in the vessel, whereby it remains in liquid phase, is blown out of the vessel through at least one nozzle by virtue of the internal pressure of said pressure vessel, and the resulting high-speed two-phase flow consisting of steam and fine water particles is directed in jet-form against the surface of said high temperature object for cooling said object.

2. A method according to claim 1, characterized in that the heating to obtain said high temperature water is accomplished by means of high temperature steam.

3. A method according to claim 1, characterized in that the heating to obtain said high temperature water is accomplished by electric heating.

4. A method according to claim 1, characterized in that the jet velocity of said two-phase flow is controlled by means of a controlling valve.

5. A method according to claim 1, characterized in that the jet velocity of said two-phase flow is controlled by adjusting the temperature in said pressure vessel.

6. A method according to claim 1, characterized in that said high temperature water is recovered below said object to be cooled and is recycled into said pressure vessel.

7. A method of cooling a high temperature object substantially as hereinbefore described with reference to the accompanying drawings.

MICHAEL BURNSIDE & PARTNERS,
Chartered Patent Agents,
Hancock House,
87 Vincent Square,
London SW1P 2PH.
Agents for the Applicants.

Printed for Her Majesty's Stationery Office, by the Courier Press, Leamington Spa, 1976.
Published by The Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.

FIG. 1

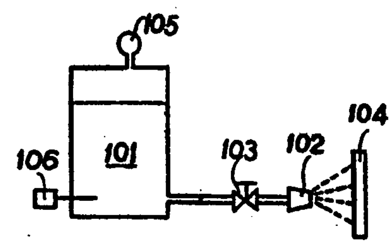

105
104
106
101
103
102

FIG. 2

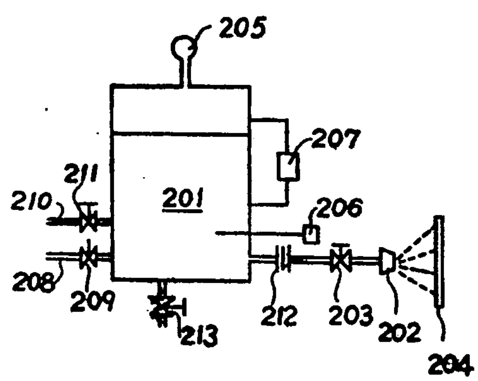

205
207
211
210
201
206
208
209
213
212
203
202
204

FIG. 3

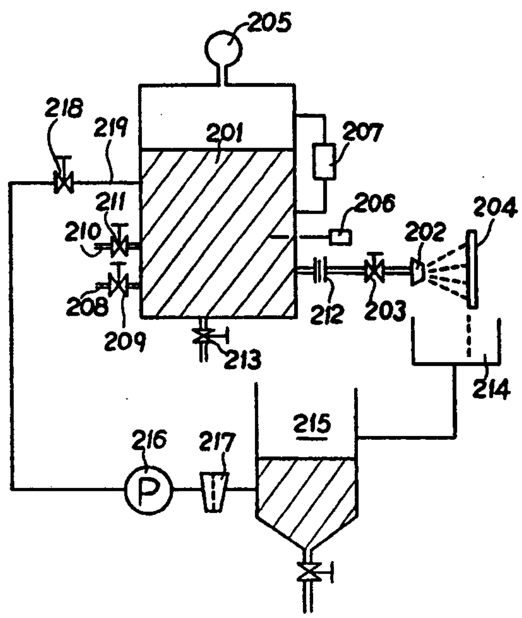
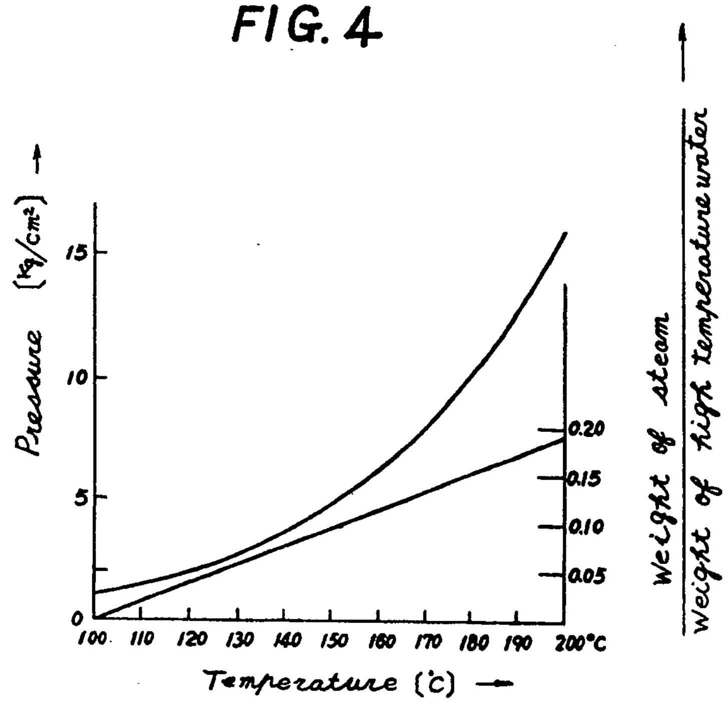

205
218
219
201
207
211
206
204
210
202
208
212
203
209
213
214
215
216
217
P

FIG. 4


Pressure (Kg/cm²)
15
10
5
0
100
110
120
130
140
150
160
170
180
190
200°C
Temperature (°C)
0.20
0.15
0.10
0.05
Weight of steam / Weight of high temperature water

1447335 COMPLETE SPECIFICATION

5 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 4

FIG. 5

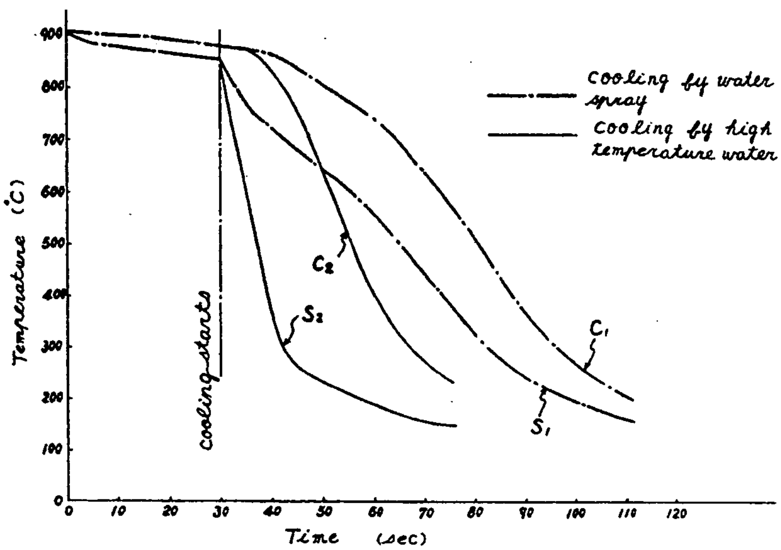
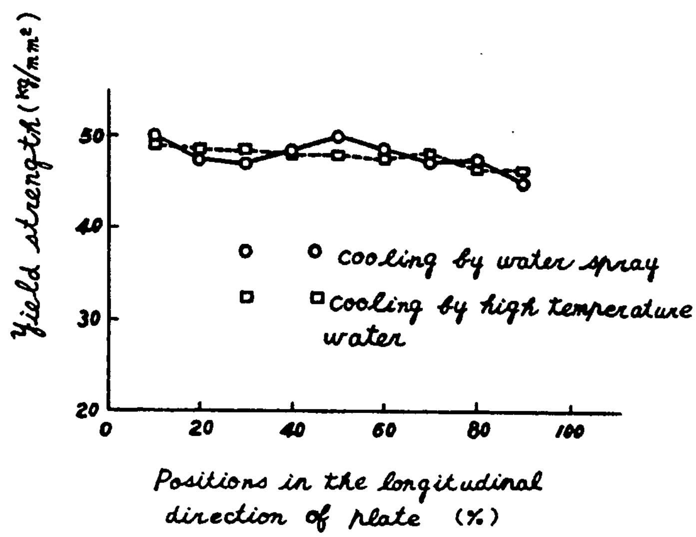


FIG. 6


Yield strength (kg/mm²)
50
40
30
20
0
20
40
60
80
100
○ cooling by water spray
□ cooling by high temperature water
Positions in the longitudinal direction of plate (%)